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Applicant(s): Andrew Knight et al.
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If it is determined that any fees are due, the Commissioner is hereby authorized and respectfully requested to charge such fee to account No. 08-2789.

Respectfully submitted,

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Dated: January 14, 2004

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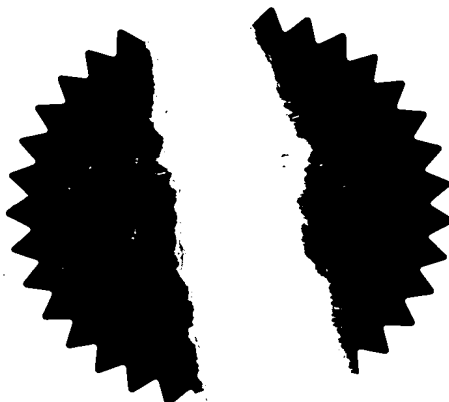
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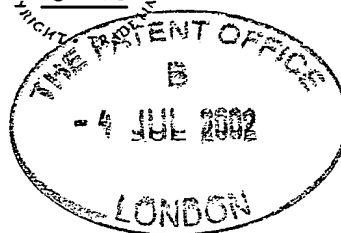
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P01/7700 0.00-0215487.0

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R071550PGB

04 JUL 2002

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Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

Delaware, United States of America

4. Title of the invention

FUEL INJECTION SYSTEM

5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

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Description 12

Claim(s) 2

Abstract

Drawing(s) 5

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Priority documents

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Statement of inventorship and right to grant of a patent (Patents Form 7/77)

Request for preliminary examination and search (Patents Form 9/77) 1

Request for substantive examination (Patents Form 10/77)

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FUEL INJECTION SYSTEM

The present invention relates to a fuel injection system for an internal combustion engine, which permits control of the injection timing and injection pressure level.

It is known to provide a fuel injector with a nozzle control valve (NCV) which is arranged to control movement of a fuel injector valve needle relative to a seating so as to control the delivery of fuel from the injector.

A known Electronic Unit Injector (EUI) includes a dedicated pump having a cam-driven plunger for raising fuel pressure within a pump chamber, and an injection nozzle through which fuel is injected into an associated engine cylinder. A spill valve is operable to control the pressure of the fuel within the pump chamber. When the spill valve is in an open position, the pump chamber communicates with a low pressure fuel reservoir so that fuel pressure within the pump chamber is not substantially affected by movement of the plunger and fuel is simply drawn into and displaced from the pump chamber as the plunger reciprocates. Closure of the spill valve causes pressure in the pump chamber to rise as the plunger is driven to reduce the volume of the pump chamber. The EUI also includes an electronically controlled nozzle control valve (NCV) which is arranged to control the timing of injection of fuel.

Although EUIs are capable of providing very high injection pressures, the accuracy of control of the injection pressure and injection timing is limited by the nature of the cam drive.

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In common rail (CR) fuel injection systems, a single pump is arranged to charge an accumulator volume, or common rail, with high pressure fuel for supply to a plurality of injectors. As in an EUI system, the timing of injection is controlled by means of a respective nozzle control valve of each injector. One advantage of the common rail system is that the timing of injection of high pressure fuel is not dependent upon a cam drive, and so fast and accurate timing of injection can be achieved with the NCVs. However, achieving very high injection pressure within a common rail system is problematic and the high levels to which fuel must be pressurised can cause high stresses within the pump and within the rail. The rail must therefore be provided with a relatively thick wall for pressure containment, making it heavy and bulky. Parasitic fuel losses can also be high.

Significant improvements in combustion quality and efficiency may be achieved by rapidly varying the injection pressure level and rate. Such pressure variations are difficult and/or inefficient to achieve with either EUI or CR systems. For example, in a CR system, a lower injection pressure can be achieved by dumping some of the high pressure fuel to a low pressure reservoir, but this is an inefficient use of pumping energy.

It is an aim of the present invention to provide a fuel injection system which substantially overcomes or alleviates at least one of the above limitations and disadvantages.

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According to the present invention there is provided a fuel injection system for supplying pressurised fuel to a fuel injector, the fuel injection system comprising:

an accumulator volume for supplying fuel at a first injectable pressure level to the fuel injector through a fuel supply passage,

pump means for increasing the pressure of fuel supplied to the injector to a second injectable pressure level, and

valve means operable between a first position in which fuel at the first injectable pressure level is supplied to the injector and a second position in which communication between the injector and the accumulator volume is broken so as to permit fuel at the second injectable pressure to be supplied to the injector.

Preferably, the pump means is arranged, at least in part, within the fuel supply passage.

One advantage of the invention is the ability to control the injection of fuel at different pressure levels, without the need to dump high pressure fuel. The system therefore has improved efficiency over known common rail fuel systems. The accumulator volume may be charged with fuel at a moderate pressure of, say, 300 bar, and the pump means may be arranged to increase rail pressure further to, say, between 2000 and 2500 bar. Within one engine cycle it is therefore possible to vary the pressure of the injected fuel (and thereby the injection rate), and this has important implications for emissions levels. For example, it has been found that a two-stage injection including a pilot injection

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of fuel at a first pressure level followed by a main injection of fuel at a higher pressure level can reduce pollutant emissions. This can be achieved relatively easily and efficiently using the fuel system of the pressure invention.

The pump means and the injector may be combined in a so-called "unit pump/injector arrangement", wherein the pump components and the injector components are arranged within a common housing.

In a preferred embodiment, the pump means include a pump chamber defined within a plunger bore, and a plunger which is movable within the plunger bore to cause pressurisation of fuel within the pump chamber when the valve means is in the second position.

The pump means is preferably driven by means of a cam arrangement.

Preferably, the injector includes a nozzle control valve which is operable to control the timing of commencement of injection at the first and/or second injectable pressure levels.

The pump means may further comprise a drive member, such as a tappet, which is cooperable with the plunger, and a cam follower for driving the drive member in response to rotation of the cam, thereby to drive plunger movement.

Preferably, the drive member is not coupled to a rocker arm of the engine but the cam bears directly on a follower associated with the plunger.

It is a further feature of the present invention that engine valve timing and fuel pressurisation can be accomplished using the same cam drive.

Preferably, the valve means is an electrically operable valve which is movable between its first and second positions by application of an electronic control signal. When the valve means is in the first position, the pump chamber communicates with the accumulator volume and when the valve means is in the second position communication between the pump chamber and the accumulator volume is broken.

The pump means may be operable to raise the fuel pressure within the pump chamber to a level of, typically, between 2000 and 2500 bar.

In a preferred embodiment, the accumulator volume takes the form of a common rail. Typically, the common rail is charged with fuel from a pump at a pressure of between 200 and 300 bar.

In another embodiment, the common rail is comprised in another engine component, for example a hollow engine rocker shaft or an engine cylinder head.

Another advantage is that, due to the provision of the pump means, fuel within the common rail need only be charged to a relatively modest pressure, and so the rail can be a thinner walled vessel or container having reduced weight and bulk. It is therefore possible to situate the common rail inside another component, for example inside a hollow rocker shaft or an engine cylinder head.

Embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 shows an arrangement of a known EUI system,

Figure 2 shows an arrangement of a known common rail fuel injection system,

Figure 3 shows an arrangement, in accordance with the invention, of a fuel injection system in a first operating state,

Figure 4 shows an arrangement, in accordance with the invention, of a fuel injection system in a second operating state,

Figure 5 shows an arrangement, in accordance with the invention, of a fuel injection system in a third operating state,

Figure 6 is a graph showing a fuel injection characteristic which is obtainable using the fuel injection system of Figures 3 to 5,

Figure 7 is another graph showing the fuel injection characteristic which is obtainable using the fuel injection system of Figures 3 to 5, and

Figure 8 shows a sectional arrangement of a practical embodiment of the fuel system in Figures 3 to 5.

By way of background to the present invention, Figures 1 and 2 show known EUI and common rail fuel systems respectively. Referring to Figure 1, a known EUI arrangement 10 includes an injector 12 and a high pressure fuel line 14 for providing a supply of fuel under pressure to a nozzle 13 of the injector 12. A nozzle control valve (NCV) 16 is arranged to control movement of a fuel

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injector valve needle (not shown) so as to control the delivery of fuel from the nozzle 13. The valve needle is engageable with a valve needle seating and movement of the valve needle away from the seating permits fuel to flow through one or more outlets of the nozzle 13 into the engine cylinder or other combustion space.

The NCV 16 is arranged within a further passage 20 in communication with the supply line 14 to control communication between the high pressure supply line 14 and an injector control chamber (not shown). The NCV 16 is movable between a first position and a second position. When the NCV 16 is in the first position, the further passage 20 communicates with the control chamber of the injector 12. When the NCV 16 is in the second position, the control chamber communicates with a low pressure reservoir (not shown) and communication between the further passage 20 and the control chamber is broken. A surface associated with the valve needle is exposed to fuel pressure within the control chamber and the pressure of fuel within the control chamber applies a force to the valve needle which serves to urge the valve needle against its seating. Operation of the NCV 16 to control fuel pressure within the control chamber therefore provides a means of controlling valve needle movement.

The EUI 10 also includes a pump 23 having a plunger 26 and a pump chamber 24. The plunger 26 is movable within a plunger bore under the influence of a cam drive arrangement 28 to cause pressurisation of fuel within the pump chamber 24. The pump chamber 24 communicates with the high pressure fuel line 14 and with a low pressure fuel reservoir (not shown), through an additional passage 30, under the control of a spill valve 32.

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In use, rotation of a cam 28 serves to urge the plunger 26 inwardly within its bore to reduce the volume of pump chamber 24. When the spill valve 32 is in an open position, the pump chamber 24 communicates with the low pressure fuel reservoir so that the pressure in the chamber 24 is not substantially affected by movement of the plunger 26 and fuel is simply drawn into and displaced from the pump chamber 24 as the plunger reciprocates. Closure of the spill valve 32 causes fuel pressure within the chamber 24 to rise as the plunger 26 is driven inwardly within its bore to reduce the volume of the pump chamber 24.

Figure 2 shows a known common rail fuel system including a plurality of fuel injectors 12a, 12b (two of which are shown), each having an associated NCVs 16a, 16b respectively and associated high pressure fuel supply passages 14a, 14b respectively in communication with a common rail 42. The common rail 42 is supplied with high pressure fuel from a common rail fuel pump 44. In use, the timing of injection of pressurised fuel is controlled by actuation of the NCVs 16a, 16b, in the same manner as described above for the EUI 10.

Referring to Figure 3, the fuel system of the present invention includes an injector 50 having a valve needle 55 and an associated high pressure supply passage 52. An NCV 54 is operable between a first position, in which an injector control chamber 57 communicates with the high pressure supply passage 52, and a second position, in which the control chamber 57 communicates with a low pressure reservoir and communication between the high pressure supply passage 52 and the control chamber 57 is broken, as described previously. A common rail pump 58 supplies fuel at a moderately high and injectable pressure level (e.g. 300 bar) to an accumulator volume in the form of a common rail 59. A pressure regulator 60 serves to maintain the

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pressure of fuel within the common rail 59 at a substantially constant level. For clarity, only one fuel injector 50 is shown in the system of Figure 3, although in practice a plurality of injectors would be supplied with fuel from the common rail 59 in a multi-cylinder engine.

The common rail 59 supplies pressurised fuel to a supply passage 61 in communication with a pump chamber 64 under the control of an electrically operable valve 62. The pump chamber 64 forms part of a pump arrangement 63, including a plunger 66 which is driven by means of a cam drive arrangement 68. The electrically operable valve 62 is actuated in response to an electronic control signal provided by the engine controller to move between open and closed positions so as to control whether pressurisation of fuel within the pump chamber 64 occurs as the plunger 66 reciprocates under the influence of the cam drive arrangement 68.

In Figure 3, the valve 62 adopts its open position in which the common rail 59 communicates with the pump chamber 64. Under such circumstances, reciprocating movement of the plunger 66 has substantially no effect on fuel pressure within the chamber 64. With the valve 62 in the open position, the pressure of fuel supplied to the injector 50 is therefore determined by the pressure of fuel within the rail 59 which, typically, will be around 300 bar. In order to inject fuel at this first, moderate pressure level (P1), the NCV 54 is moved into its open position (as shown in Figure 4), causing fuel pressure within the control chamber 57 to be reduced and thereby enabling the valve needle to lift, as described previously.

Figure 5 shows the same system as in Figures 3 and 4, but in which the valve 62 has been moved into its closed position to break communication between

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the supply line 61 from the common rail 59 and the pump chamber 64. With the valve 62 closed, reciprocal movement of the plunger 66 under the influence of the cam 68 will cause fuel within the pump chamber 64 to be increased to a second injectable pressure level (P2), which is greater than the first pressure level (P1). Typically, the second pressure level is between 2000 and 2500 bar. By opening the NCV 54 the valve needle is lifted from its seating, as described previously, to permit injection at this higher pressure level, P2.

Thus, the timing of injection of fuel at the first, moderate pressure level is controlled by operation of the NCV 54 while the valve 62 is open. The timing of injection of fuel at the second, higher pressure level is controlled by operation of the NCV 54 while the valve 62 is closed, in which circumstances the pump arrangement 63 serves to increase the pressure of fuel supplied by the common rail 59 to the second higher pressure level.

It is a particular advantage of the present invention that an injection event comprising a pilot injection of fuel at a first, relatively low pressure level followed by a main injection event at a second, higher pressure level can be achieved. It has been found that this combination of a pilot and a main injection provides benefits for emission levels.

Figure 6 shows an example of the injection rate R of fuel as a function of time T , for an injection event including a pilot injection of fuel followed by a main injection of fuel. It will be appreciated that the injection rate for any given injection nozzle will depend upon the pressure of fuel supplied to the nozzle.

Referring to Figure 6, the initial pilot injection of fuel, A, at a rate $R1$ is achieved by injecting fuel at moderate rail pressure, $P1$, for a short duration

followed by a main injection of fuel, B, at a higher rate R2 and pressure level P2. The injection rate R1 is achieved by holding the valve 62 open whilst the NCV 54 is moved into its open position to cause the valve needle to lift. The pilot injection of fuel is terminated by closing the NCV 54 to re-establish high pressure fuel within the control chamber 57, thereby causing the valve needle to be seated.

Injection at the second, higher pressure level, P2, is generated by closing the valve 62 such that the pump arrangement 63 causes fuel pressure within the pump chamber 64 to be increased to a level higher than that within the rail 59. The NCV 54 is opened to commence the main injection of fuel, B, at the second pressure level, P2 and is closed to terminate the main injection, as described previously.

It has also been found that a main injection of fuel having a so-called "boot-shaped" injection characteristic, as shown in Figure 7, provides particular benefits for emissions. A boot-shaped main injection includes an initial injection of fuel, C, at a first rate R1 (rail pressure P1) followed by an injection of fuel at a higher rate, R2 (pump chamber pressure, P2) and is achieved by moving the valve 62 between its open position (rail pressure P1) and its closed position (increased pressure P2) whilst the NCV 54 is held open to maintain the needle in its lifted position.

One practical embodiment of the fuel system in Figures 3 to 5 is shown in Figure 8, in which corresponding features are denoted with the same reference numerals. A cam follower 70 rides over the surface of the cam 68 as the cam rotates and is arranged to impart drive to a drive member 72, for example in the form of a tappet, coupled to the plunger 66. The drive member 72 is driven

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under the influence of the cam arrangement 68, 70 to reciprocate within a cylinder 74 and, thus, imparts reciprocating movement to the plunger 66. A pin 80 is secured to the drive member 72, and a return spring 78 is mounted upon a shaft 76 of the engine which cooperates with the pin 80 so as to return the drive member 72 and follower mechanism as the follower 70 rides over the falling flank of the cam 68. The plunger 66 is arranged to be substantially perpendicular to the axis of the injector.

As can be seen in Figure 8, the diameter of the common rail 59 is smaller than that of the rocker shaft 76. It is possible to use a common rail 59 of relatively small size, as it need only be charged with fuel at the first, moderate pressure level due to the provision of the pump arrangement 63 and the valve 62 which permit an increased pressure level to be supplied to the injector 50 when the valve 62 is closed. By way of example, the moderate pressure of fuel within the rail may be around 300 bar, compared with pressures around 2000 bar in known common rail systems. As the common rail 59 may be of relatively small size, it is possible to house the rail 59 within another component of the engine. For example the shaft may be the engine rocker shaft 76 and may be hollow. The rail may extend through a region of the hollow shaft, or alternatively the rail may be provided within a region of an engine cylinder head.

CLAIMS

1. A fuel injection system for supplying pressurised fuel to a fuel injector, the fuel injection system comprising:

an accumulator volume for supplying fuel at a first injectable pressure level to the fuel injector through a fuel supply passage,

pump means for increasing the pressure of fuel supplied to the injector to a second injectable pressure level, and

valve means operable between a first position in which fuel at the first injectable pressure level is supplied to the injector and a second position in which communication between the injector and the accumulator volume is broken so as to permit fuel at the second injectable pressure to be supplied to the injector.

2. The fuel injection system of claim 1, wherein the pump means and the injector are combined in a unit pump/injector arrangement.

3. The fuel injection system of claim 1 or claim 2, wherein the pump means is driven by means of a cam drive arrangement.

4. The fuel injection system of any of claims 1 to 3, wherein the pump means include a pump chamber defined within a plunger bore, and a plunger which is movable within the plunger bore to cause pressurisation of fuel within the pump chamber when the valve means is in the second position.

5. The fuel injection system of claim 4, wherein the pump means further comprise a drive member which is cooperable with the plunger, and a cam drive arrangement for driving the drive member in response to rotation of a cam, thereby to impart drive to the plunger.
6. The fuel injection system of claim 5, wherein the drive member is coupled to a rocker arm of the engine such that movement of the drive member imparts pivotal movement to the rocker arm.
7. The fuel injection system of any of claims 1 to 6, wherein the injector includes a nozzle control valve which is operable to control the timing of commencement of injection at the first and/or second injectable pressure levels.
8. The fuel injection system of any preceding claim, wherein the valve means is an electrically operable valve which is movable between its first and second positions by application of an electronic control signal.
9. The fuel injection system of any preceding claim wherein the pump means is operable to raise fuel pressure to a second injectable pressure level in the range of 2000 and 2500 bar.
10. The fuel injection system of any preceding claim, wherein the fuel in the common rail is at a pressure level of between 200 and 300 bar.
11. The fuel injection system of any preceding claim, wherein the common rail is comprised in a rocker shaft of the associated engine.

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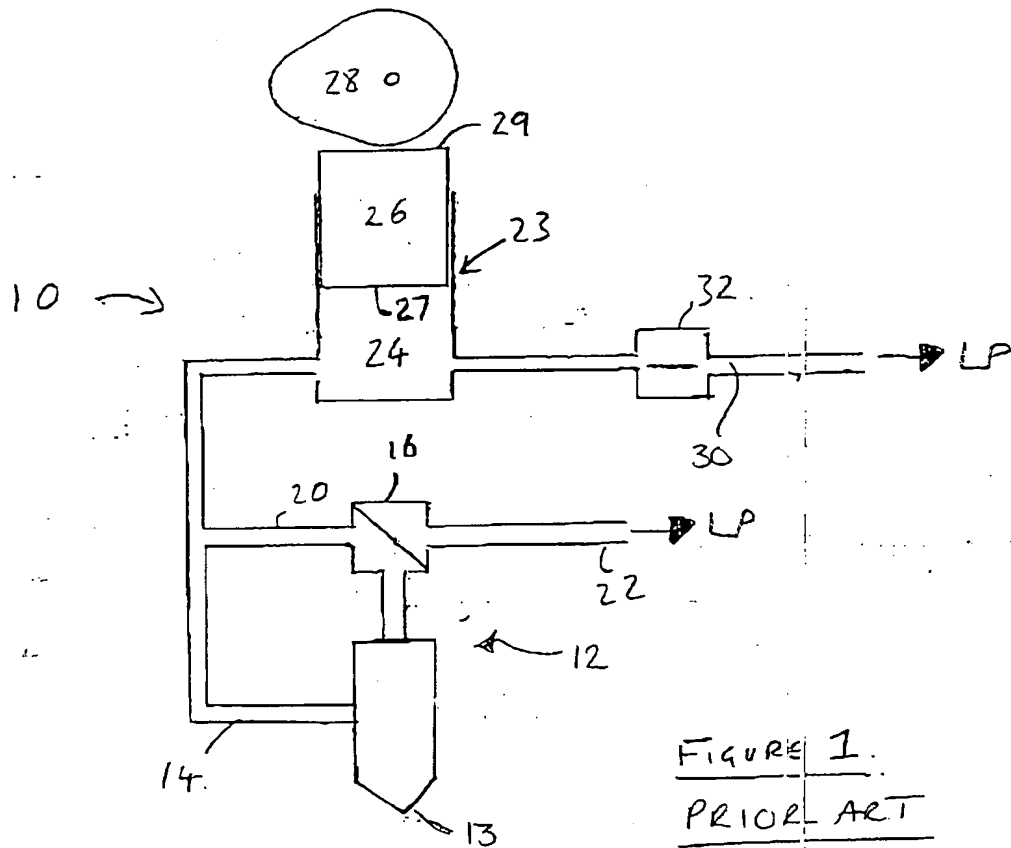
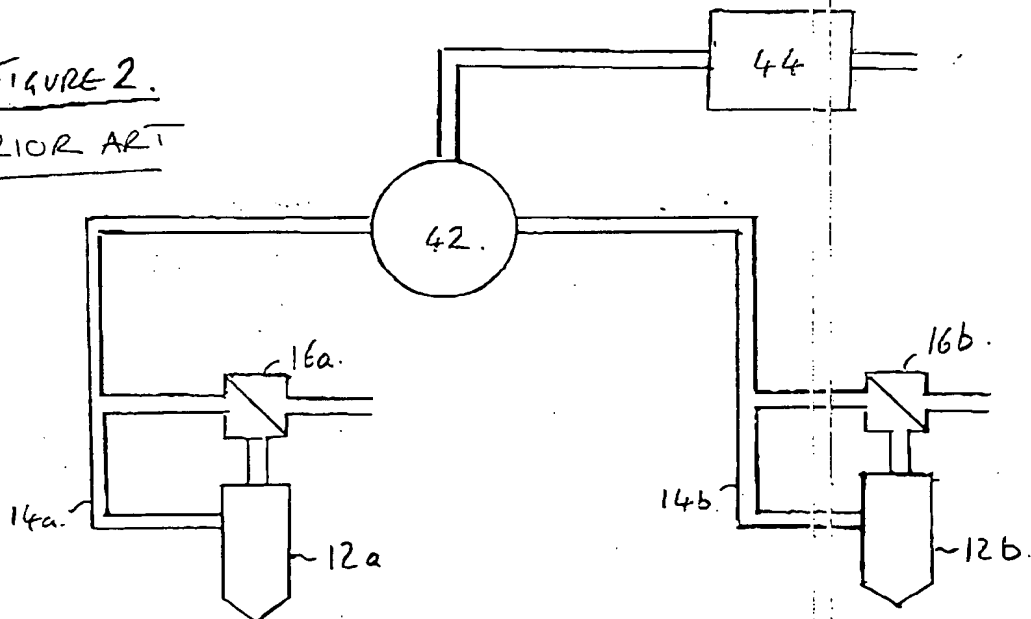


FIGURE 2.
PRIOR ART





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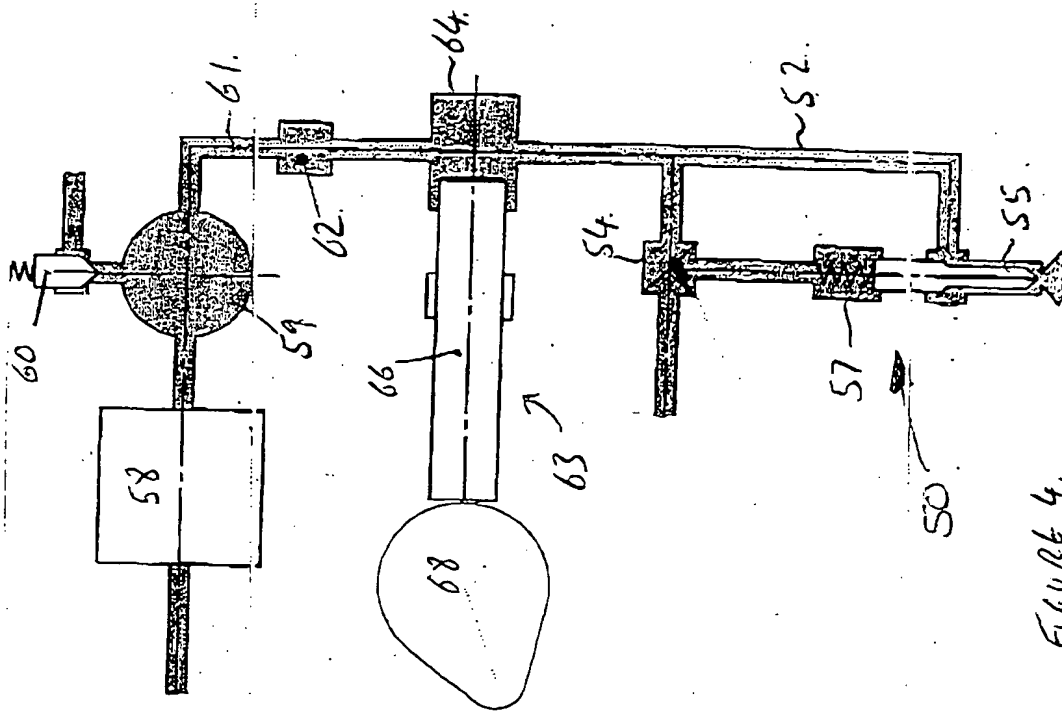


FIGURE 4.

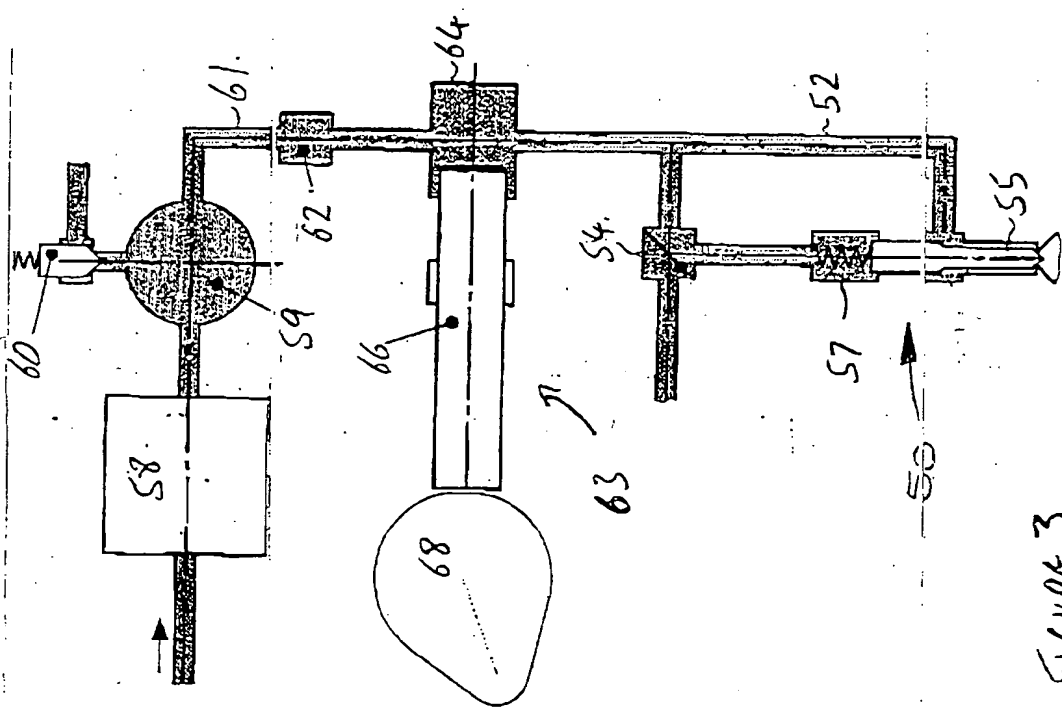


FIGURE 3.



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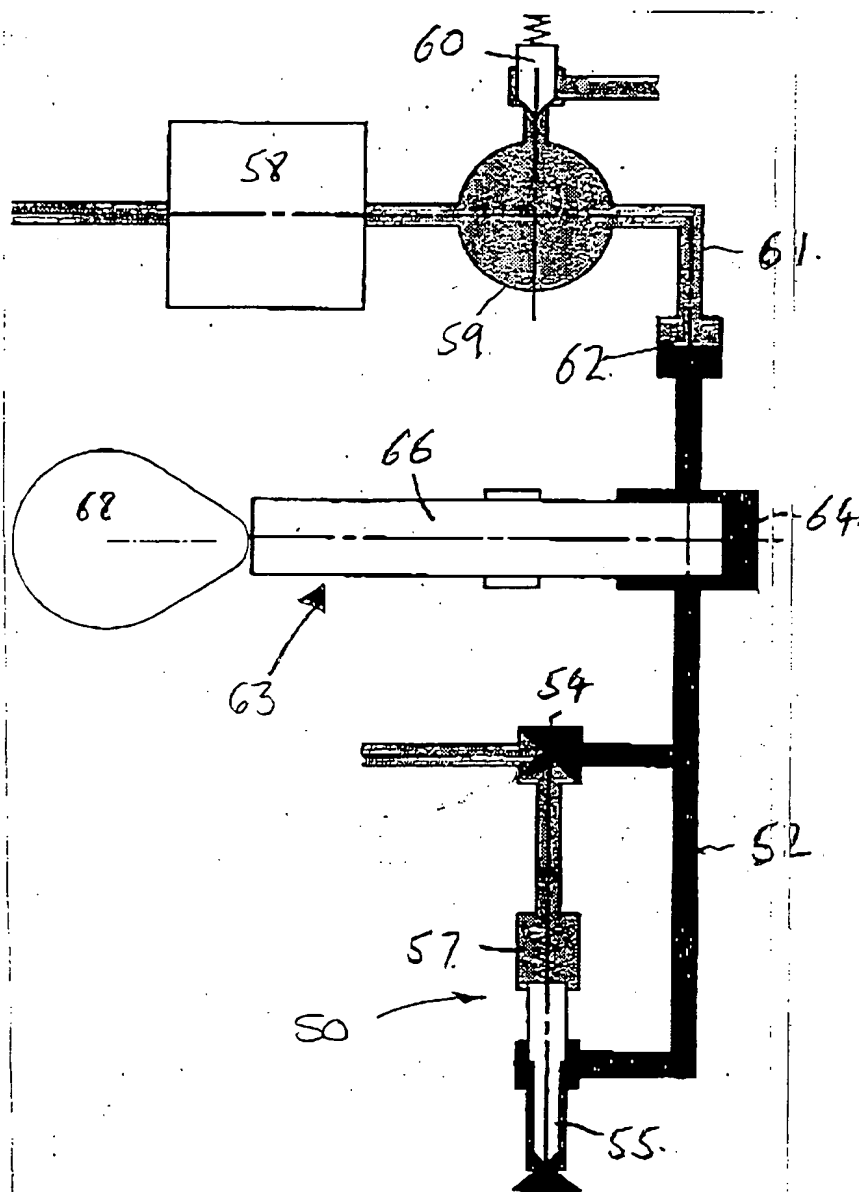
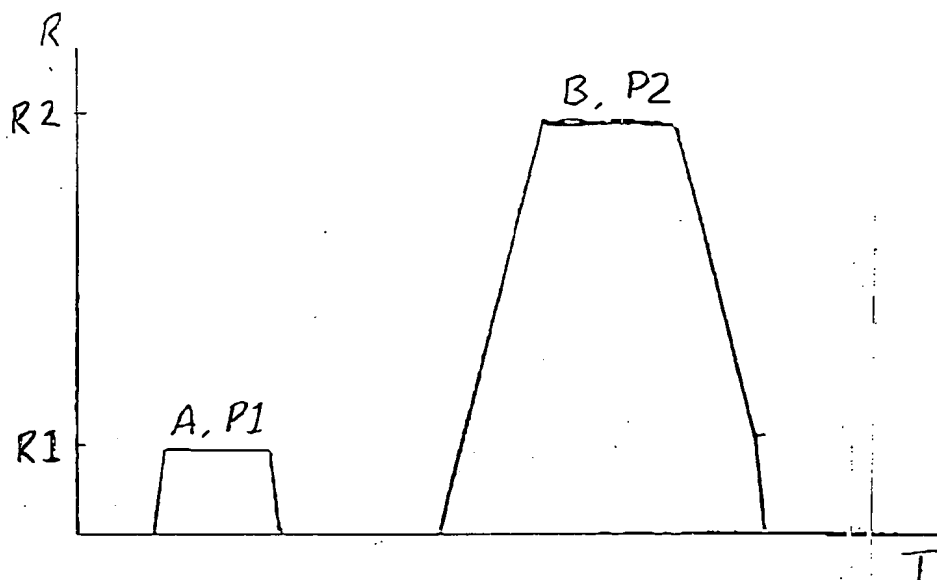
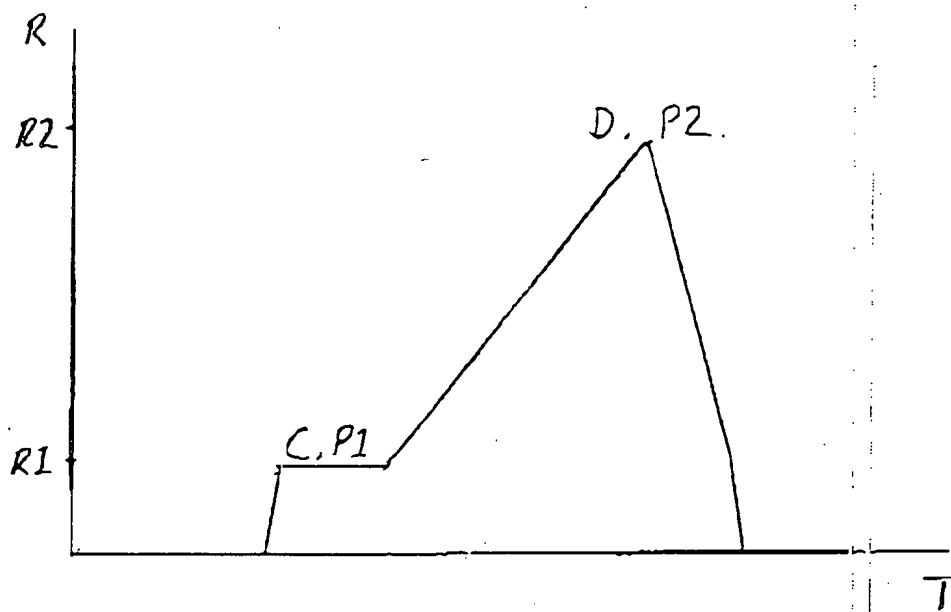


FIGURE 5.



FIGURE 6.FIGURE 7.



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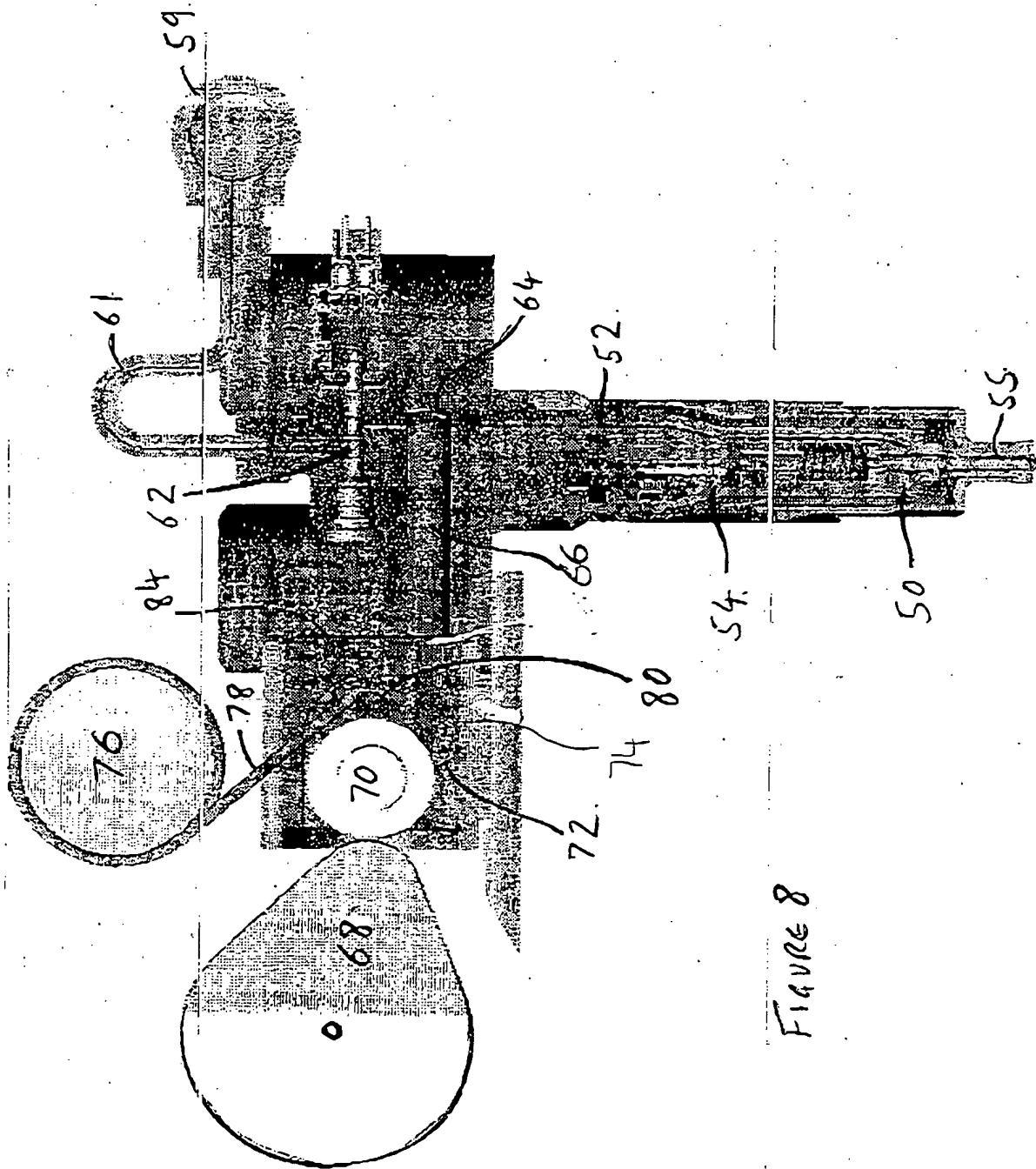


FIGURE 8

